isocentric rotational delivery (DIR) where the gantry moves to multiple positions and delivers a ray of spots with various energies from each fixed gantry position without lateral beam scanning. A cylindrical water phantom with a cylindrical target (3.3cm length, 5cm diameter) in the middle of the phantom has been chosen. For 3DSS also a lung tumour patient case has been evaluated. For both cases a dose of 60Gy was prescribed to the CTV in a single fraction. Spot positions and weights were derived and the dose was recalculated with a dose calculation algorithm. For each delivery method and case two plans were derived: one with the isocenter (IC) positioned in the middle of a CT-voxel andone with the IC shifted by 0.4 (0.3)mm (CT grid: Δx=Δy=Δz=1mm) for the cylinder phantom (patient) relative to the IC in each direction simulating a small setup error.

Results: Table 1 summarizes the minimal doses to 1%, 50% and 95% of the target. The most robust method shows to be the 3DSS. Particularly for the water phantom the dose differences are minor. However, this is not valid for the patient case. Here, even with 3DSS the minimal dose to 95% of the volume was reduced by almost 3Gy due to the IC shift. Furthermore, local dose differences up to almost 8% within the target and 3mm distant (cc direction) to the IC were found. Generally, the dose differences between the two plans are most obvious within the gradient region. The DET methodis less robust. The general trend is the same as for the 3DSS case but absolute local differences are up to almost 5Gy at 14mm distant from the IC slice. With this technique the dose differences are mainly in the gradient region of the dose distribution. The DIR method is most sensitive to the setup-errors, where the beam rotates around the IC without lateral scanning. The IC shift therefore shifts the dose distribution in the same direction for all beams. Therefore, the detrimental effects can accumulate. Dose differences for the two plans are up to 7% even within the IC slice.

Delivery technique	Patient/Phantom	Target point shift [mm]	$D_{1\%}$	$D_{50\%}$	$D_{95\%}$
3D spot-scanning	Phantom	(0|0|0)	60.02	59.80	58.46
		(0.4|0.4|0.4)	60.26	59.79	58.36
3D spot-scanning	Patient (lung)	(0|0|0)	60.51	59.85	59.32
		(0.3|0.3|0.3)	60.93	59.63	56.47
DET	Phantom	(0|0|0)	63.61	59.95	56.36
		(0.4|0.4|0.4)	63.90	59.91	56.43
DET, multilayer (3)	Phantom	(0|0|0)	62.05	59.92	58.59
		(0.4|0.4|0.4)	62.54	59.91	58.29
DIR	Phantom	(0|0|0)	61.64	59.97	58.69
		(0.4|0.4|0.4)	64.27	59.56	56.91

Conclusions: The results show that even very small setup errors that cannot be completely avoided through image guidance can influence the resulting dose distributions depending on the delivery method for proton therapy. However, the presented results assume a single fraction delivery which is not the usual clinical practice but illustrates the effect best. For fractionated treatment the effects should be reduced, however, based on the presented results, studies evaluating the residual effects with particular respect to the applied delivery technique are required.

PO-0852

Interfractional variation in position of pancreatic tumors measured with daily CBCT using fiducial markers

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Purpose/Objective: IMRT and VMAT for RT of pancreatic cancer can reduce toxicity to OARs such as stomach, small intestines and kidneys, but the tight conformity of the high-dose surface to the target area in these techniques requires highly accurate positioning. Daily cone-beam CT (CBCT) enables pretreatment correction of patient setup errors. The pancreas shows considerable day-to-day positional variation relative to the vertebrae, which can introduce substantial systematic and random setup errors. The use of intratumoral fiducial markers, visible on CBCT, can help reduce the setup errors and decrease the currently large PTV. The aim of our study is to quantify interfractional variation in tumor position using fiducials and CBCT and thus determine the potential benefit of using intratumoral fiducials rather than bony anatomy for daily pancreatic patient setup verification.

Materials and Methods: Eleven consecutive pancreatic cancer patients were included in our study and each received 2 to 3 gold fiducial markers (Visicoil; 0.35 mm diameter) by endoscopic ultrasound-guided implantation. The two markers of one patient could later not be located on the reference CT. In the other 10 patients, a total of 25 markers were visible on the CT as well as on all CBCTs. For these patients, who received 25 × 2Gy, a total of 242 CBCTs were registered with the reference CT on bony anatomy and on each of the markers. From this, the displacement of markers relative to the vertebrae was determined, as well as the distance between marker pairs. Marker migration, tissue deformation and marker localization error all affect the distance between two markers. To validate the use of the fiducial markers as indicator of tumor position, we analyzed the 20 marker pair distances using linear fits to the CBCT data.

Results: Pair distances showed only slight trends (mean slope of -0.03 mm/day, range -0.10 to 0.02 mm/day, 5/20 with $p<0.05$), most likely due to tissue deformation (shrinkage), but no clear shifts that would indicate marker migration. The residuals of the linear fits had a mean SD of 0.8 mm (range 0.4–1.3 mm), a measure for localization error. From the positional variation, we found for these ten patients an SD of systematic error Σ of 4.0, 5.3 and 3.6 mm and an SD of random error σ of 3.6, 4.9, and 2.3 mm, in LR, SI and AP, respectively. See the Figure for the distributions in the SI-direction.

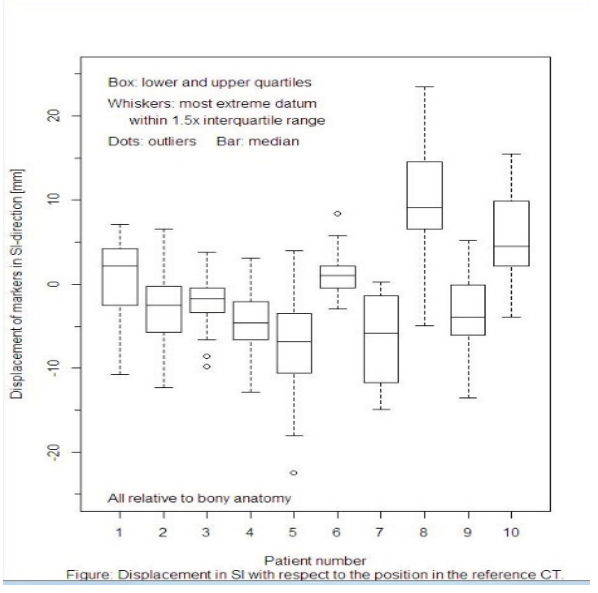

Figure: Displacement in SI with respect to the position in the reference CT

For 11% (26/242) of fractions, the vector displacement relative to bony anatomy was >15mm; 29% (69/242) showed a vector displacement >10mm. For one patient the vector displacement for 72% (18/25) of fractions was >10mm.

Conclusions: This study of interfractional variation of pancreatic tumor position shows large mean displacements (systematic errors) in addition to a wide spread in positional range between patients. This strongly supports the benefit of on-line position verification based on the tumor itself rather than on bony anatomy, and hence the necessity of implantation of intratumoral fiducial markers.

PO-0853

Cumulated dose estimation in prostate IGRT: Is it necessary to recalculate the dose for each fraction?

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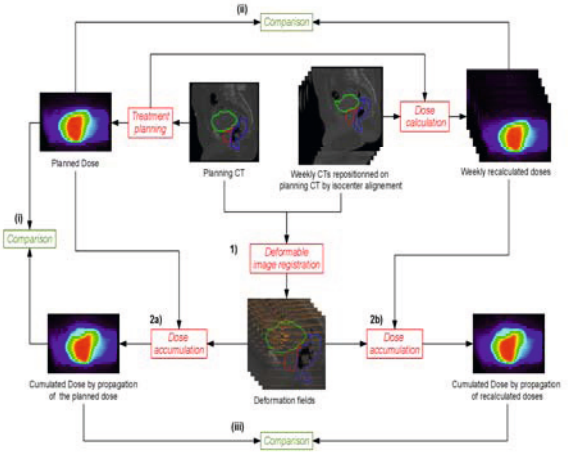
Purpose/Objective: In the context of dose accumulation in prostate IGRT, most proposed methods assume that the fraction dose can be approximated by a propagation of the planned dose. The objectives of this study were to quantify the uncertainties resulting from this approximation.

Materials and Methods:



20 patients receiving 80Gy with prostate IGRT underwent one planning CT and 8 weekly CTs. The prostate, seminal vesicles (SV) and OARs were manually delineated by one expert on all CT datasets. An IMRT treatment plan was generated on each planning CT. Deformable registration was used in order to estimate the actually delivered dose during the treatment. An in-house registration method, using the manually delineated contours, was used in order to register weekly CTs to the planning CT. The resulting deformation fields were used to propagate the dose distributions on weekly CTs and obtain the weekly cumulative doses. Two methods were used to obtain the dose distributions on weekly CTs: They were either approximated by the planned dose or recalculated according to the treatment parameters. We quantified the differences between: (i) the recalculated dose distributions at each fraction and the propagated planned dose; (ii) the cumulated dose by using propagation of the planned dose (C1) and the cumulated dose by using the recalculated doses (C2); (iii) the planned dose distribution (P) and cumulated dose distributions(C1 and C2). (figure)

Results: Small differences (mean difference <1Gy for all patients and all organs) were observed between the planned dose after propagation and the weekly recalculated dose. The maximal difference observed in the patient cohort was 3.7Gy, 6.1Gy, and 8.5Gy for the prostate, bladder and rectum, respectively. The largest differences observed in the rectum were caused by the presence or absence of gas. The mean Dice scores after registration were 0.93±0.01, 0.85±0.05, 0.95±0.02, and 0.93±0.02 for the prostate, SV, bladder, and rectum, respectively. Considering the two cumulated doses C1 and C2, the mean differences between mean doses (Gy) within the prostate, SV, bladder and rectum wall were 0.14±0.45, 0.10±0.40, 0.11±0.34, and 0.08±0.22, respectively. The point-by-point absolute dose differences were less than 2.1Gy, 3.1Gy, and 3.9Gy for the prostate, bladder, and rectum, respectively. Considering the difference between C1 and the planned dose P, the mean differences between the mean doses (Gy) within the prostate, SV, bladder wall and rectum wall were -0.07±0.13, -0.35±1.50, 0.44±7.91, and -0.98±2.03, respectively. The absolute difference reached 15.6Gy for the bladder wall and 6.3Gyfor the rectum wall. Similar differences were observed when considering C2.

Conclusions: For prostate IGRT, approximating the dose distribution at each fraction by the planned dose distribution has a low impact on cumulated dose estimation. Conversely, the cumulated dose in the rectum and bladder can be dramatically higher than the planned dose.

PO-0854

Adapting head and neck clinical target volumes using atlas based auto-segmentation software

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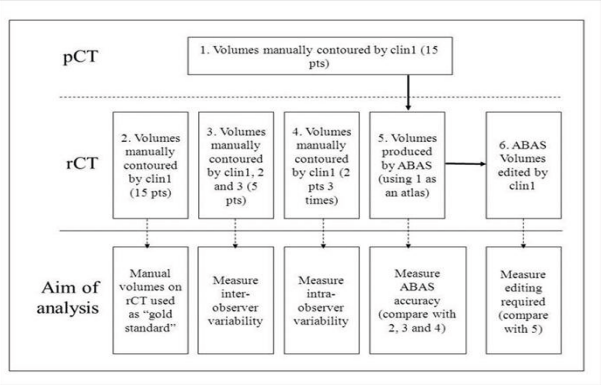
Purpose/Objective: Delineation of CTVs on a planning CT (pCT) by clinicians for head and neck cancer is time consuming (>2hrs/patient). When patients change shape during treatment (i.e. weight loss) then CTVs must be re-delineated on a replan CT (rCT). Deformable image registration software can register pCT to rCT to allow transfer of pCT volumes to rCT. The aim of this work was to 1) assess the accuracy of segmenting CTVs on rCT using atlas based automatic segmentation (ABAS) and compare accuracy with inter- and intra-observer variability 2) estimate time savings.

Materials and Methods: Fifteen patients (pt) with both pCT and rCT were selected. One clinician (clin) delineated high dose (HD) and low dose (LD) CTVs on pCT and up to 3 clin on 3 occasions delineated CTVs on rCT. CTVs, delineated on pCT manually, were used as an atlas for ABAS to segment volumes on rCT. Finally, one clin edited ABAS CTVs so they were clinically acceptable. A flowchart of volumes produced is shown in figure 1. Steps 2 and 6 were timed to estimate time savings using ABAS. CTVs were compared using mean distance to agreement (MDA), dice similarity coefficient (DSC) and normalised dice coefficient (nDSC). nDSC is DSC divided by an uncertainty index, the DSC between the manual volume and the manual volume reduced uniformly by a set distance. This distance was set as the mean inter-observer MDA (2mm). nDSC is an important parameter as, unlike DSC, it does not have a volume size dependence. nDSC> 1 indicates volumes agree within an uncertainty of 2mm. Figure 1. Flow chart of the manually delineated and ABAS segmented contours on both the pCT and rCT as well as the aims of the analysis from each step.



Results: Volume comparison results for both CTV_{HD} and CTV_{LD} are shown in table 1. Inter-observer variability was higher than intra-observer variability but both led to MDA < 2.3mm. The inter- and intra-observer variability of delineating CTV_{HD} was lower for CTV_{LD} as CTV_{HD} generally contained more, well-defined, boundaries, whereas, particularly the inferior aspects of CTV_{LD}, were less well defined by anatomical boundaries. ABAS contours were found to agree with manual delineations to within inter-observer variability when both MDA and nDSC were considered. However some minor editing was required. The mean(1SD) times taken by a clinician to both delineate and edit ABAS CTVs were 169min (25min) and 57min (11min) respectively.

Table 1. Results showing the mean volume comparison results (MDA, DSC and nDSC) for inter- and intra-observer variability as well as comparing manual volumes against both ABAS segmented volumes and edited ABAS segmented volumes.

Volumes being compared	CTVHD			CTVLD		
	MDA (SD) (mm)	DSC	nDSC	MDA (SD) (mm)	DSC	nDSC
Inter-observer	2.01 (1.72)	0.86	1.13	2.26 (1.92)	0.72	0.92
Intra-observer	1.27 (1.23)	0.91	1.12	1.59 (1.52)	0.86	1.06
Manual vs. ABAS	2.14 (1.85)	0.85	1.11	2.28 (1.99)	0.79	1.08
Manual vs. edited ABAS	1.83 (1.86)	0.86	1.13	1.82 (1.72)	0.81	1.11

Conclusions: Inter-observer variability in CTV delineation was higher than intra-observer variability and ABAS volumes were mostly within inter-observer variability. This analysis did not identify small local differences in contours of clinical importance, for which ABAS volumes required minor editing. A time saving of approximately 67% was achieved by editing ABAS produced CTV volumes compared to full manual delineation.